Carcass and Meat Quality of Llama

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Executive summary

1. Twelve 2 to 3 year old llamas were sourced from Alberta and Saskatchewan, and slaughtered at the Lacombe Research Centre meat laboratory to obtain fundamental information on carcass and meat quality of the llama to assist the llama industry in promoting llama meat as an alternative source of protein.

2. A second objective was to assess the efficacy of aging in vacuum and high voltage electrical stimulation (HVES) in reducing variability in tenderness of llama meat.

3. A third objective was to obtain baseline physiological data and to assess the physiological response of llama to pre-slaughter transport and handling.

4. Average live weight of the study animals was 129.5 kg and warm carcass weight was 75.6 kg. Warm carcass yield thus averaged 58.4% but had a range of 54 to 61%, reflecting differences in duration of transport and time off feed prior to slaughter.

5. Average proportion of lean in the carcass, as determined by cut out, was 68.3%, but there was a 13% range in lowest to highest lean yields. Most of the difference in fat content was in the intermuscular fat depot, but degree of finish varied as well. Typical Canada 1 yield grade beef carcasses cut out similarly in other trials had an average lean content of 61.8%.

6. Content of marbling fat was relatively low, and the protein content of 22.66% for uncooked rib eye muscle trimmed of fat was higher than reported figures for the raw lean tissue of beef (21.7%) or pork (21.07%).

7. Muscle color of the rib eye at grading time was darker, less saturated (less intense color, grayer) and more purplish red compared to the bright, cherry red desired in beef muscle. A number of samples, mainly from control sides, had "dark-cutting" characteristics. Muscle pH was higher than normal beef or pork muscle and,

especially for control sides, indicative of the dark-cutting condition. HVES had a beneficial impact on pH decline and muscle color.

8. Five different cuts were aged in vacuum for 3, 7 or 14 days to determine the effect of aging on tenderness. Longer aging times reduced shear values (more tender) of grilled steaks on average. However, the results were not consistent and, depending on the particular cut, 25 to 50% of samples from non-stimulated sides did not benefit from additional aging beyond 3 days.

9. HVES of the carcass side at 50 min post-mortem resulted in grilled loin chops which were more tender than their counterparts from the control side, and the differences in average shear value were highly significant ($P<0.0001$) for each of the three aging periods. Nonetheless, the results were not totally consistent and, at each aging period, there were one or two carcasses of the twelve in which HVES did not produce a response.

10. HVES combined with aging beyond 3 days provided the most consistent and efficacious results for reduction of shear values. Only one sample from the stimulated sides did not benefit from additional aging, and it was already tender after 3 days of aging.

11. Five muscles were initially identified as having the shape and size to have potential for fabrication into chops or medallions: loin eye, rib eye, inside round, outside round and eye of round. The outside round was found to be too tough, even following 14 days of aging, to be a good candidate for medallions without marinating to improve its texture. In this study, the eye of round was found to be the most tender, followed by the inside round, loin eye and rib eye steaks. Given the chilling conditions carcasses were subjected to in the study, it is recommended that HVES and 14 days of aging be utilized to reduce variation in tenderness.

12. The microbiological condition of the carcass following washing was found to be comparable to the dressing of beef carcasses, and better than the dressing of lamb carcasses processed in the same facility.

13. Baseline salivary cortisol levels were very low, and when the animals were transported, unlike many other species, did not show a huge stress response. The data from these 12 animals suggest that pre-slaughter stress may not be as great in this species as in cattle, pigs or elk. Consequently, meat quality aberrations caused by physiological response to pre-slaughter stress may be less of a concern in llama.

Introduction

There are currently approximately 12,000 llamas registered in Canada, the majority of which are located in Alberta and B.C. There are an unknown number of males lacking in breeding quality (e.g. low fiber, poor conformation, poor legs) which are not registered, as well as other animals which the owners have not bothered to register, so the total number of llamas may be considerably higher. To date, the Canadian llama industry has been restricted to breeding of animals but as the population of llamas increases it is becoming increasingly necessary to find an alternative market for young, cull males. In Bolivia the llama is raised mainly for its meat while the alpaca is kept for its fine wool (Sammells). Llama meat is much more common in the countryside (often as charqui, an intermediate moisture jerky) than in the cities where it is the poorer people and those who recently migrated to the city from rural areas who purchase and eat llama meat. Many middle class and wealthy Bolivians disdain llama meat as being unclean and the food of the poor. It's reputation for being unclean derives from the meat being primarily sold in outdoor markets which are generally dirtier and lack refrigeration compared to indoor meat markets frequented by those who can afford higher priced meats.

Some llama producers in this country are now slaughtering young, cull males for meat for their own use. The meat has been found to be of variable quality with respect to tenderness (Shelley Bevans, personal communication). Before the llama industry can hope to begin promoting llama meat as an alternative source of protein, either in Canada or in export markets, it is necessary to obtain some fundamental information on carcass content, meat quality of various cuts, and composition relative to traditional red meats. During a recent convention of the Canadian Llama and Alpaca Association (Red Deer, AB, October 14/15, 2000), a number of producers expressed a common interest and willingness to cooperate in working towards this goal. The objective of this small study then was to obtain basic data on the carcass and meat quality of the llama. It should be emphasized that some caution should be applied in that it is difficult to characterize an entire species from twelve animals.

Objectives

1. To determine the carcass characteristics and general meat quality of llama.

2. To identify those muscles of the llama carcass suitable for chops or medallions, and classify them according to relative tenderness.

3. To determine the effect of high voltage electrical stimulation and aging in vacuum on tenderness of llama meat.

4. To determine the effect of pre-slaughter transport and handling on salivary cortisol levels.

Methods

Carcass assessment and effect of HVES

Twelve young (2 – 3 years old), cull male llamas were obtained from various producers in Alberta. The animals were shipped to the Lacombe Research Centre abattoir and held overnight in separate pens with access to water but not feed. Live animal weights were obtained immediately prior to slaughter and carcass weights were recorded following the dressing procedure. Animals were not sheared prior to slaughter. Following evisceration, the carcass was split and muscle pH and temperature was measured in the rib eye muscle (longissimus thoracis, LT) of both carcass sides at 50 min post-stunning. Alternating right and left carcass sides were assigned to control (C) or high voltage electrical stimulation (HVES) treatment. After chilling overnight at 1 to 2°C, both carcass sides were knife-ribbed between the 11th and 12th ribs to expose the rib eye muscle for assessment. Color of the LT of both sides was measured following a 20 min bloom period using a Minolta

CR-300 reflectance meter and pH/temperature measurements repeated. Subjective observations were made of muscle color, texture, and firmness using 7 point scales adapted from the American Meat Science Association guidelines for assessing beef (American Meat Science Association, 1990). Texture refers to the "grain" or the apparent fineness or coarseness of the muscle and is a function of the size of the muscle fiber bundles. Firmness refers to the relative firmness or softness of the muscle and is assessed visually and by tactile observation. The degree of marbling at the 11^{th} rib was also assessed visually using the USDA/Canadian beef marbling standards. Descriptions of these subjective scoring systems are provided below.

Table 1. AMSA descriptive terms for subjective scoring of muscle color, texture and firmness.

Score	Color	Texture	Firmness
7	Very light cherry red	Very fine	Very firm
6	Cherry red	Fine	Firm
5	Slightly dark red	Moderately fine	Moderately firm
4	Moderately dark red	Slightly fine	Slightly soft
3	Dark red	Slightly coarse	Soft
2	Very dark red	Coarse	Very soft
1	Black	Very coarse	Extremely soft

Table 2. USDA marbling descriptors.

AMSA Score	Description
100	Devoid
200	Practically devoid
300	Traces
400	Slight
500	Small
600	Modest
700	Moderate
800	Slightly abundant
900	Moderately abundant
1000	Abundant
1100	Very abundant

The control side of each carcass was cut into primal cuts which were further reduced to determine proportion of lean, fat and bone. Fat depots included body cavity fat (fat on the inside of the body cavity of the carcass), subcutaneous fat (fat on the outside of the carcass, beneath the hide) and intermuscular fat (fat deposited between individual muscles of the carcass). These three fat depots were combined to obtain total dissectable fat. The front quarter was separated into 5 pieces: a 4-bone **chuck** with the brisket attached; the **shank**, separated from the chuck at the elbow; the **neck**, separated from the chuck at the 5^{th} – 6^{th} vertebrae; a 7-bone **rib** (2 x 3); and **plate**. The hind quarter was separated into three primals: the **round** or hip was separated from the long loin by sawing at a right angle to the long axis one inch below the aitch bone; and the **long loin** and **flank** were separated along a straight line passing one inch from the edge of the loin eye at both ends.

The loin eye muscle (longisssimus thoracis et lumborum) was collected from both sides of the carcass to determine the effect of HVES on meat quality. A 20 mm thick chop was cut from the 12^{th} rib end to determine drip loss in a retail display tray over a 48 h period. Six consecutive chops of 30 mm thickness were then cut and packaged under vacuum (multivaced) for subsequent shear value determination. Chops were paired to randomize muscle location with aging treatment, and aged for different periods (3, 7 or 14 d) prior to freezing (-25°C).

Frozen chops were thawed for 24 h at 4°C prior to cooking. The chops were cooked on a Garland grill to 35°C, flipped and cooked to 70°C. They were then chilled in an ice/water bath to arrest the cooking process, and held overnight at 4°C. Two cores of 19 mm diameter were removed from each chop and sheared at right angles to the grain in a Warner-Bratzler shear cell. Peak shear force required to shear through the cores was recorded.

Identification of muscles suitable for chops or medallions

From the cut out side (control side) muscles in addition to the loin eye were identified which were considered to have potential for fabrication into chops or medallions because of their size and shape. The additional cuts (muscles) selected were: rib eye steaks (longissimus thoracis), inside round (semimembranosus), outside round (biceps femoris) and eye of round (semitendinosus). The chops were mutivaced, aged for three different periods and cooked similarly to the procedure for the loin samples.

Proximate analyses

The rib eye muscle (LT) from the HVES side was collected, trimmed of external fat, ground and mixed three times. A 100 g sub-sample was used to determine moisture content by drying in a convection oven for 24 h at 102°C. The resultant dried product was used for determination of ether-extractable fat (Tecator Soxtec Fat Extraction System) and protein content (Leco Nitrogen Analyzer).

Determination of stress levels

Baseline levels of salivary cortisol were determined from samples collected from selected animals prior to shipment. Further samples were collected at the Lacombe Research Centre abattoir to determine the effect of pre-slaughter transport and handling on salivary cortisol levels.

Microbiological condition of the dressed carcass

Twenty-five random samples were collected from each of the 24 carcass sides following processing and washing. The samples were collected by swabbing a delimited area of 10

cm^2 using sterile guaze. The samples were then processed using the QA Life Sciences Hydrophobic Grid technique. From each sample the total plate count (TPC), total coliforms and *E. coli* were enumerated.

Results and Discussion

Carcass characteristics and yields of llama.

Final live weight of the twelve animals slaughtered in this trial ranged from 98 kg to 146 kg (Table 4). Average live weight was 129.5 kg and average weight of the hot carcass was 75.6 kg, giving a mean warm carcass yield expressed as a percentage of final (shrunk) live weight of 58.4%. There was a considerable range in carcass yield (54 to 61%), which reflects the differences each test animal experienced in duration of travel and time off feed prior to slaughter. Carcass shrinkage during cooling averaged 1.36%, which is similar to the rate of shrinkage encountered for beef carcasses in the same cooler.

The relative proportions of tissues in the carcass as determined from cut outs are presented in Table 5. While the proportion of lean in the carcass averaged 68.3%, even within this small group of animals, there was a 13% spread in lean content between the lowest and highest yielding carcasses, ranging from 60.4 to 73.7%. Mean values for proportion of bone and readily-separable fat were 17.3% and 14.4%, respectively. Most of the difference between carcasses in fat content was in the intermuscular fat depot, but degree of external finish varied as well (Table 5). In contrast, forty-one typical Canada 1 yield grade beef carcasses, which were cut out at the Lacombe Research Centre, had an average lean content of 61.8% and fat content of 21.3%. The range in lean content of the beef carcasses was similar in magnitude to that of the llamas at 11% (56 – 67%). A

carcass breakdown chart for llama is provided in Table 7, which shows the distribution of lean, fat and bone in the primal cuts based on information derived from these 12 animals. It should be recognized that lean does not reflect all of the salable product in the carcass, and total salable yield from the carcass would vary with the cut out specifications, i.e. bone-in or bone-out, and the amount of fat left on or in sub-primal cuts.

Composition of the rib eye muscle (longissimus thoracis)

Proximate analyses of the uncooked, externally defatted rib eye muscle resulted in mean values for moisture, intramuscular fat and protein of 75.0, 1.31 and 22.66%, respectively (Table 6). The range in intramuscular fat content was 0.88 to 2.50 and is indicative of the narrow range of marbling scores assigned to the rib eye exposed at the 11^{th} rib at time of carcass appraisal. All carcasses except one were assessed as being devoid or practically devoid of marbling while the remaining carcass was assessed a marbling score of slight, very much at the low end of the marbling scale used for beef. By way of comparison, 42.6% of all beef carcasses graded in Canada in 2000 had marbling scores of small or greater. Despite years of research, however, there is still considerable debate as to the effect of marbling on palatability traits of red meats (Jeremiah, 1996). It is generally agreed that marbling has positive effects on palatability attributes but accounts for only a small portion of the variation in tenderness while having a greater impact on juiciness and overall palatability. The other side of the coin, of course, is the ability to promote a lean product as being a healthier source of protein, and llama, like other alternative species such as deer and elk, fit that description.

There was a fairly wide range in protein content of the rib eye muscle of this limited group of animals (21.09 – 23.42%). The average of 22.66% is higher than the average protein content of 21.7% for 23 raw beef cuts trimmed of visible fat (Beef Information Centre), and higher than the protein content of 21.07% for composite samples of raw, fresh separable lean from retail pork cuts (USDA). Our findings support reports in the

popular press that llama meat has a low fat content and higher protein content than beef (Sammells).

Meat quality attributes of llama and the effect of high voltage electrical stimulation

The meat quality attributes of the loin eye muscle from both sides of the carcass were examined to determine the fundamental meat characteristics of llama and to determine the effect of high voltage electrical stimulation on important muscle properties. In the post-mortem period, during the conversion of muscle to meat, biochemical activity (glycolysis) in the muscle produces lactic acid in the absence of oxygen which is no longer supplied through the vascular system. This build up of lactic acid lowers the pH of the muscle. The rate and extent of glycolysis in the post-mortem period impacts meat quality, particularly color and water holding properties but can also affect tenderness. Muscle pH, then, is measured in the early post-mortem period (50 min in this study) to determine the rate of glycolysis, and later (24 or 48 h, generally) to determine the extent of glycolysis. A number of factors can have an effect on muscle glycolysis in the post-mortem period including: species, type of muscle, physiological status of the animal prior to and at the time of slaughter (environmental conditions, stress), and carcass treatments (e.g. rate of cooling, electrical stimulation). Typically, muscle pH declines from 7.2 to about 6.2 in the first hour post-mortem (Murray, 1995) and ultimate pH levels are normally in the range 5.4 to 5.6 for beef and pork. If muscle glycogen levels are very low due to chronic stress prior to slaughter then the fuel is not there for glycolysis to proceed, and pH decline can be much less. Ultimate pH over 6.0 is associated with dark, firm, dry (DFD) meat. DFD meat is undesirable because the dark color is discriminated against, and shelf life is shortened because spoilage bacteria flourish at the higher pH. In addition, in beef, there is some evidence that beef muscle with an ultimate pH between 5.8 and 6.2 has a greater likelihood of being tough compared to beef having an ultimate pH below or above that range (Jeremiah *et al.*, 1991). As can be seen from the average pH figures provided in Table 8, the rate of glycolysis was slow in the early post-mortem period, and

the extent of glycolysis was limited with control sides having a mean 24 h pH of 6.02. HVES had a significant impact on pH decline with treated sides having a 24 h pH of 5.80.

HVES also had a beneficial influence on instrumentally-measured muscle color (Table 8). The rib eye muscle was brighter and the color was more highly saturated (chroma) in treated sides compared to control sides, although hue was unaffected. Using the same equipment and similar bloom times, typical L* (brightness) values obtained for non-stimulated beef rib eye muscle are in the range of 34 to 36.5 (Aalhus *et al.*, 2000) compared to the average L* for control sides and stimulated sides of 29.4 and 31.9, respectively, for llama rib eye muscle. Chroma and hue angle are also typically higher for beef. Thus beef, which qualifies for the Canada A grade series, has a brighter, more highly saturated color with more of the cherry red hue compared to the darker, less intense color and more purplish-red hue of the llama in this trial. The objective measurements obtained in this study for llama are more closely related to results obtained for conventionally chilled, non-stimulated elk rib eye muscle: 28.1, 17.4 and 20.3 for L*, chroma and hue angle, respectively (Robertson *et al.*, 2000). In an elk study, conditioning the carcass at 6°C instead of conventionally chilling at 1 to 2°C increased brightness (L*) and saturation (chroma) at time of grading.

While the Minolta meter used to measure color is a very sensitive instrument capable of detecting small differences, subjective color scores were also affected by HVES. The HVES sides had a higher proportion of bright, cherry red color score while the control sides had a much higher proportion of dark red or very dark red color scores (Table 9). Beef carcasses with dark red or very dark red muscle color would be downgraded and heavily discounted. Carcasses with moderately dark red muscle color generally brighten up sufficiently with longer bloom times to qualify for the Canada A grade series, but bright, cherry red color at the time of grading is far more preferred. There is some awkwardness in using subjective color scales designed for beef for assessing muscle color of other species, and the authors are not suggesting that llama meat should look like beef. However, the results here, along with the objective color measurements and 24 h

pH values obtained, do indicate a high incidence of dark cutting, high pH meat especially for control sides (42%). With longer bloom times, muscle color was observed to improve.

The texture of the rib eye muscle was found to be moderately fine or fine and generally firm with some variation in firmness from slightly soft to firm. These are desirable traits. Drip loss, which is used as a measure of water holding capacity of the muscle, was unaffected by HVES treatment.

Effect of aging on tenderness of llama chops and medallions.

Tenderness has been identified as the most important palatability attribute of meat and, consequently, the primary determinant of meat quality (Huffman *et al.*, 1996). The effect of aging in vacuum for 3, 7 or 14 days on tenderness of llama meat was examined for five different cuts derived from the control (non-stimulated) side of each carcass. The cuts chosen were the loin eye, rib eye, inside round, outside round and eye of round. The cuts were chosen for their potential as sources of chops or medallions based on shape and size of the muscle. The tenderloin was not chosen because it was very small in diameter, and in any event, tenderness should not be an issue.

On average, aging for 14 days reduced shear values (more tender) for the various cuts by 13% to 30% compared to aging for only 3 days (Tables 10 and 11). While the differences in average shear values between 14 and 3 days of aging were statistically significant ($P<0.05$), the effect of aging was inconsistent. One of the drawbacks to working with a small sample size is the fact that large differences in a couple of samples can skew the data and so it becomes necessary to look beyond the mean values to draw valid conclusions. In this case, extended aging produced dramatic results in a few samples while 25% to 50% of samples, depending on the particular cut, did not respond to aging at all. Shaded cells in the tables indicate samples which did not respond to aging. Rib eye

steaks were the only exception where all samples aged for 14 days were more tender than samples aged for 3 days.

Average shear values of steaks aged for 7 days were not significantly different from those of 3 day aged steaks, with the exception of rib eye steaks which improved by 16% with the additional aging time. Improvements in average shear values obtained by increasing aging time from 7 to 14 days were only statistically significant ($P<0.05$) for the loin eye and rib eye steaks. Again, the effect was inconsistent with some samples not benefiting from additional aging.

It is intriguing to note from the shear values provided in Tables 10 and 11, that the inside round and eye of round were found to be more tender than the loin eye and rib eye chops. This is possibly due to rapid chilling rate of the loin and rib muscles compared to the larger mass of the hip. Under light load, the meat facility drip cooler is a very efficient carcass chilling system. In a previous study with elk, chilling the carcass at 6°C instead of 1°C lowered mean shear values and reduced within animal variation in shear values (Robertson *et al.*, 2000). A modified temperature conditioning treatment would likely be more efficacious for those muscles more prone to rapid temperature decline.

Effect of high voltage electrical stimulation and aging on tenderness

Llama carcasses, and other alternative species such as deer and elk, are more lightly muscled and lack the insulating fat cover of beef carcasses. Consequently muscle temperature declines more rapidly, and this has consequences for meat quality, particularly tenderness. One of the underlying mechanisms of cold-induced toughening is thought to be cold shortening (Locker and Hagyard, 1963). The general rule for prevention of cold shortening is not to allow the carcass muscles to cool below 10°C in the first 10 h post-mortem (Bendall, 1972). From the chart in Appendix 1, we can see the temperature of the rib eye muscle of the test carcasses fell below 10°C (log 1.0) within

four hours post-mortem. There are three practices which can be employed alone or in combination to reduce the risk of cold-induced toughening:

1) modified or high temperature conditioning of the carcass to avoid the critical temperature zone,
2) application of high voltage electrical stimulation to the carcass before entry to the chiller, and
3) modified suspension (e.g. suspending the carcass from the aitch bone instead of the Achilles tendon) to increase the tension on the more highly valued cuts.

In experiments with farmed whitetail deer and elk at the Lacombe Research Centre, high voltage electrical stimulation was found to be ineffective in reducing shear values of venison (unpublished data), which is in stark contrast to results with beef (Aalhus *et al.*, 1994). However, high temperature conditioning at 10°C for deer carcasses and 6°C for elk carcasses was found to be efficacious in the reduction of shear values of the rib eye muscle (Robertson *et al.*, 2000). It is impossible with 12 animals to try everything, and it was decided to examine the effects of high voltage electrical stimulation in this trial. One of the mechanisms by which HVES lessens cold-induced toughening is the depletion of energy reserves in the muscles prior to chilling, thereby preventing muscle contraction and cold shortening. Additionally, it is thought that HVES causes disruption of the muscle structure by causing stretching and tearing of the myofibers, and by releasing lysosomal enzymes (Pearson and Dutson, 1985). Muscle pH falls faster during the early stages post-mortem and rigor mortis occurs sooner than in non-stimulated muscles. The added benefit of using HVES, is improved muscle color and, in beef at least, enhanced marbling scores at time of grading.

The effect of high voltage electrical stimulation on tenderness of grilled loin chops aged for three different time periods is presented in Table 12. On average, shear values of loin chops aged for 3 days derived from stimulated sides were 21% lower (more tender) compared to samples from non-stimulated sides. Improvement in average shear values due to HVES were greater at 28 – 29% for samples aged for longer periods of 7 or 14 days. The difference in average shear values between stimulated and control samples was

highly significant ($P<0.0001$) for each aging period. Nonetheless, the results were not totally consistent in that, at each aging period, there were one or two carcasses of the twelve in the study in which HVES failed to impact the shear values of the loin muscle.

The results are more promising and more consistent when considering the combined impact of HVES and aging on shear values (Table 13). The average shear value of loin chops from stimulated sides was reduced by 12% with 7 days of aging, and by 22% with 14 days of aging compared to aging for only 3 days. Only one sample (# 108) did not benefit from additional aging, and this sample was already tender at 3 days.

Microbiological condition of llama carcasses after washing

In determining the microbiological status, total plate counts (TPC) are an indication of the overall hygienic condition of the carcass. Coliforms are used as an indicator of fecal contamination. The presence of *E. coli* may indicate contamination by pathogenic organisms including *Salmonella* and/or pathogenic strains of *E. coli*. However, it is important to remember that not all *E. coli* are human pathogens. The microbiological status of the study carcasses following processing and washing is presented in Table 3, following.

The condition of the meat is preferably decided by reference to values for Log A. However, when the number of samples from which bacteria are not recovered (no) is greater than 5, estimates of the mean, standard deviation, and Log A are uncertain and values for those statistics should not be considered. Then, the condition of the meat is decided by reference to values for N.

Table 3. Total plate counts, coliforms and *E. coli* recovered from washed llama carcasses.

	TPC	Log TPC/cm^2	Total Coliforms	Log Total Coliforms/ 100 cm^2	Total *E. coli*	Log Total *E. coli*/ 100 cm^2
Mean[1]		1.15		-0.39		-0.39
Std. Dev.[2]		0.82		0.39		0.39
Log A[3]		1.93		-0.21		-0.21
Sum of[4]	1330.3		25		25	
N[5]	3.12		1.40		1.40	
no[6]	0		22		22	

[1] Mean = mean of the log numbers

[2] Std. Dev. = Standard deviation of the mean log numbers

[3] LogA = Log of the arithmetic mean

[4] Sum of = Sum of the total number recovered from all samples

[5] N = Log of the total number recovered from all samples

[6] no = The number of samples from which bacteria were not recovered

A study performed at the Lacombe Research Centre Meat Facility (i.e. the same facility in which the llamas were slaughtered and processed) similarly evaluated 18 sides of beef carcasses after washing. Based on this study it is a reasonable assumption that the dressing of llama carcasses from unsheared animals can be comparable with the dressing of beef carcasses with respect to microbiological contamination, but substantially better than the dressing of lamb carcasses.

Stress physiology

We have examined the physiology data for the llamas from the trial pertaining to hematology, differential blood cell counts and salivary cortisol. We have data for the animals both before and following transport to the Lacombe Meats Centre. To date, we have completed analysis for salivary cortisol (we will provide the differential count data etc when it becomes available). The salivary cortisol value represents the amount of "free" or unbound cortisol in an animal that is able to interact with tissues and cause catabolic or breakdown effects. For animals like cattle, swine or even elk we typically see the values double or even triple following a transport stress. For example cattle values for salivary cortisol pre-transport are typically 2.5 nmol/L, 4.5-6 for swine and 2-6 for elk. By contrast, the post-transport values we have measured for cattle are typically 4-5.5 nmol/L, for pigs 10-12 nmol/L and for elk 12-14 nmol/L (nano moles per liter of saliva). This increase in cortisol of course can cause unwanted meat quality aberrations in turn.

For the llama samples we measured baseline or pre-transport salivary cortisol values of 1.85 nmol/L and post transport values of 2.52 nmol/L. In other words, the llamas displayed very low salivary cortisol levels to begin with and then when transported, unlike many other species, did not show a huge stress response. This may be reflecting their degree of habituation with humans and management procedures in general or it may be inherent to their stress response strategy. Nonetheless, what the data suggests so far is that if these 12 animals are representative, pre-slaughter stress such as transport may not be as great in this species. This would be a positive finding in terms of stress induced alterations to meat quality. However, like many scientists, I would caution that this is a fairly small sample of animals.

Having indicated that pre-slaughter stress can lead to meat quality aberrations such as dark cutting, and noting the low salivary cortisol levels and lack of significant stress response of the study animals, how can we explain the prevalence of high pH, dark meat observed? It is possible to theorize the animals had a low level of glycogen to begin with,

but the extent of physical contraction of the musculature during the application of HVES would suggest that a lack of glycogen and ATP is not the explanation.

From a biological perspective, high pH meat classically means that the glycogen pool (available glucose) is depleted. Indeed for animals like pigs and cows this has been demonstrated especially in high stress and DFD situations. However, one could think of this situation also as one in which there is a low glucose but not necessarily because glycogen is depleted. Glycolysis will typically occur in animals when, and only when, there are the correct HPA catabolic triggers. In other words, beta adrenergic agonists and cortisol must express themselves and then the various glycogenic enzymes must respond. If either HPA axis activity is low, as would appear to have been the case with the llamas, or glycolysis is not highly active despite the level of HPA activity, one can well envision a situation where glycogen may be present but its breakdown is moderated. Indeed in humans, this is a combination desired and trained for in endurance athletes such as long distance runners and Xcountry distance events. Whereas, shorter high energy demand events such as wrestling or Judo often train for a quick release and breakdown of glycogen.

When one thinks of where llamas evolved, high altitude, another factor may also be present. At high altitude with low oxygen an animal may not be able to support high energy (glucose) events even if they wanted because they simply could not provide the oxygen needed to sustain such activity. Hence, the llama may have a genetic predisposition to only breaking down its glycogen slowly even if it has a good supply or even if there is an apparent high need. In addition, there would likely be an interaction here with different muscle fiber types.

Mammalian muscle tissue is made up of long cells called myofibers. Myofibers occur in three types: red, white and intermediate. Red myofibers are narrow, richly supplied with capillaries, are rich in the oxygen binding myoglobin pigment, and thus are adapted for aerobic metabolism (i.e. requires oxygen). The internal membranes, called sarcoplasmic reticuli, which act as binding sites for glycolytic enzymes are poorly developed in red

myofibers. Red myofibers are adapted to operate over long periods of time without rest. White fibers, on the other hand, are broader in diameter, myoglobin poor, produce energy through anaerobic metabolism (i.e. doesn't require oxygen), have well developed sarcoplasmic reticuli and large amounts of stored glycogen. White myofibers are adapted to operate in short, fast bursts (Aalhus, 1995; Swatland, 2001). Different species and different muscles within the same animal have varying proportions of red, white and intermediate fibers which, in itself will affect muscle color directly, but will also affect the rate and extent of pH decline which will have an impact on the ultimate color of the meat. Llamas, which are adapted to high altitude living and low oxygen levels, may have very high proportions of red myofibers in their skeletal musculature. Thus, as indicated, part of the answer to the low rate of glycolysis during the conversion of muscle to meat may be that llama lack the "biochemical machinery" to sustain high rates of glycolysis in the anaerobic state following exsanguination.

Conclusions and implications

While one must be careful not to make too board of observations from a study with 12 animals, this study has done what it set out to do – provide some foundation of basic information on the carcass and meat quality of llama, where no information was available before. The carcasses from the 12 animals in the study were lean and the meat sampled had low levels of intramuscular fat and higher protein contents than beef or pork. While initial results suggest that llama do not react physiologically to pre-slaughter stress in the same manner as other species, high pH, dark colored meat may still be an issue in the absence of intervention technologies. High voltage electrical stimulation of the carcass combined with aging is recommended to improve tenderness and reduce variation in tenderness, until such time as other treatments can be evaluated.

Not unexpectedly for an initial study, as many questions were generated as information learned. Certainly, there is variability in carcass composition, even within this limited group of animals, and so development of a system for yield grading carcasses to reflect value would be a consideration. The study animals were deliberately selected in a narrow age band to facilitate the design of a viable experiment – how does animal age affect carcass composition and meat quality? Are age and color important attributes that could be part of a quality grading system? Does the relatively high pH of llama meat reduce storage and shelf life? Would a moderate, high temperature conditioning treatment of the carcass to slow chilling rates be effective in reducing shear values, particularly in the loin and rib eye muscles? Would the conditioning treatment accelerate muscle pH decline and improve muscle color following onset of rigor? Would low voltage stimulation applied during exsanguination of the carcass reduce ultimate pH and improve muscle color? It would certainly be of interest to determine the type of muscles cells which make up llama muscles, and their glycolytic potential with a view to helping explain the dark cutting condition in the seeming absence of stress response. And certainly, not the least important, what are the palatability attributes of llama meat, and how are these attributes affected by the aforementioned factors and treatments?

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Tables

Table 4. Live and carcass weights.

Parameter	Mean	Range
Final live weight, kg	129.5	98.0 – 146.0
Hot carcass weight	75.6	57.8 – 83.0
Carcass yield, % of final live weight	58.4	53.7 – 61.1
Cooler shrink, %	1.36	0.52 – 2.07

Table 5. Carcass composition

Tissue, %	Mean	Range
Lean	68.3	60.4 – 73.7
Bone	17.3	15.0 – 22.2
Total dissectable fat	14.4	8.6 – 24.6
Fat depots:		
Body cavity fat	1.0	0.7 – 1.4
Subcutaneous fat	4.1	1.9 – 7.6
Intermuscular fat	9.3	5.9 – 16.1

Table 6. Composition of externally defatted rib eye muscle (longissimus thoracis)

Constituent, %	Mean	Range
Moisture	75.0	74.2 – 76.2
Ether-extractable fat	1.31	0.88 – 2.50
Protein	22.66	21.09 – 23.42

Table 7. Llama carcass breakdown chart (n = 12).

Cold side weight: 37.4 kg

Cut	Tissue weights, kg				
	Rough primal	**Lean**	**Fat**	**Bone**	**Sum**
***Hind*[1]:**					
Round[2]	10.11	7.90	0.60	1.59	10.09
Long loin[3]	5.14	3.71	0.50	0.90	5.11
Flank	1.45	0.96	0.47	0.02	1.45
Front:					
Chuck[4]	10.08	6.63	1.89	1.54	10.06
Rib[5]	2.76	1.67	0.57	0.52	2.76
Neck[6]	3.38	2.05	0.51	0.80	3.36
Shank	1.38	0.73	0.09	0.57	1.39
Plate	2.85	1.59	0.78	0.48	2.85
Total wt.	**37.15**	**25.24**	**5.41**	**6.42**	**37.07**
Cutting loss	0.25				0.33
Total	37.4				37.4

[1] Carcass knife-ribbed between 11th and 12th ribs.

[2] Round separated from long loin with a straight line 1" below the aitch bone.

[3] Long loin separated from flank on a straight line passing 1" from loin eye at both ends.

[4] Four-bone chuck with brisket attached.

[5] 2 x 3, seven-bone rib

[6] Neck separated from chuck at 5th – 6th vertebrae.

Table 8. Meat quality characteristics of loin eye muscle (longissimus lumborum)

Trait	Post-mortem treatment		
	Control	HVES	Prob.
pH 50 min	6.95	6.97	0.40
pH 24 h	6.02	5.80	0.0001
Drip loss in chop, %	2.92	2.44	0.15
Color:			
L* (brightness)	29.4	31.9	0.0008
Chroma	15.1	17.5	0.002
Hue angle	19.8	20.2	0.42
Subjective scores:			
Color (1 – 7)	4.0	4.7	0.006
Firmness (1 – 7)	6.6	6.6	-
Texture (1 – 7)	6.0	5.7	0.16

Table 9. Distribution of subjective color scores for the rib eye muscle at grading time.

Score	Description	Post-mortem treatment	
		Control	HVES
2	Very dark red	1	0
3	Dark red	4	1
4	Moderately dark red	3	6
5	Slightly dark red	2	1
6	Cherry red	2	4
Total		12	12

Table 10. Effect of aging on shear values (kg) of loin eye and rib eye steaks.

Carcass #	Loin eye steaks			Rib eye steaks		
	Aging period (days)			Aging period (days)		
	3	7	14	3	7	14
101	9.483	7.695	10.849	10.683	10.429	7.042
102	11.070	9.880	11.515	11.735	8.065	7.168
103	9.446	10.661	10.073	15.063	10.364	10.453
104	12.780	10.404	7.277	11.423	11.115	8.068
105	10.893	11.188	9.160	15.458	10.356	11.279
106	10.231	8.967	8.226	9.201	8.145	6.875
107	13.180	14.422	10.966	15.160	11.143	9.952
108	7.594	7.069	8.533	8.188	6.506	6.556
109	8.732	10.536	6.866	12.306	12.213	8.951
110	11.996	7.953	6.253	11.878	9.792	8.172
111	7.437	10.293	7.746	9.205	8.614	6.333
112	9.823	10.781	9.056	12.208	12.618	9.269
LSMean	10.222*a*	9.987*a*	8.877*b*	11.875*a*	9.946*b*	8.343*c*

abc Least square means within steak type with different letters are significantly different ($P<0.05$).

11. Effect of aging on shear values (kg) of muscles from the hip.

Carcass #	Inside round			Outside round			Eye of round		
	Aging period (days)			Aging period (days)			Aging period (days)		
	3	7	14	3	7	14	3	7	14
101	10.962	8.630	7.294	10.915	12.503	9.508	12.354	8.344	5.651
102	7.523	6.569	9.343	13.373	11.050	10.563	7.332	7.914	4.785
103	13.363	14.420	9.310	13.227	10.491	8.625	8.052	5.577	5.466
104	5.471	4.765	8.473	10.229	8.818	8.806	4.620	7.255	6.246
105	6.777	6.878	6.518	10.792	11.599	9.713	7.603	8.211	6.222
106	6.995	6.739	5.365	15.073	12.097	12.504	10.248	7.639	7.788
107	10.041	7.611	4.734	12.877	14.940	14.660	7.604	8.756	7.860
108	7.341	6.367	5.634	13.660	13.067	11.523	8.355	8.464	7.322
109	7.783	7.608	6.360	8.880	9.397	8.085	6.725	5.634	6.755
110	7.098	5.257	5.813	11.572	9.566	9.085	8.178	11.330	5.886
111	6.697	7.985	5.630	11.878	12.110	11.570	6.294	5.695	6.261
112	8.958	8.766	7.704	11.913	8.000	8.833	6.638	5.501	5.784
LSMean	8.251*a*	7.633*ab*	6.848*b*	12.032*a*	11.136*ab*	10.290*b*	7.833*a*	7.527*ab*	6.335*b*

ab Least square means within steak type with different letters are significantly different ($P<0.05$).

Table 10. Effect of aging on shear values (kg) of loin eye and rib eye steaks.

Carcass #	Loin eye steaks			Rib eye steaks		
	Aging period (days)			Aging period (days)		
	3	7	14	3	7	14
101	9.483	7.695	10.849	10.683	10.429	7.042
102	11.070	9.880	11.515	11.735	8.065	7.168
103	9.446	10.661	10.073	15.063	10.364	10.453
104	12.780	10.404	7.277	11.423	11.115	8.068
105	10.893	11.188	9.160	15.458	10.356	11.279
106	10.231	8.967	8.226	9.201	8.145	6.875
107	13.180	14.422	10.966	15.160	11.143	9.952
108	7.594	7.069	8.533	8.188	6.506	6.556
109	8.732	10.536	6.866	12.306	12.213	8.951
110	11.996	7.953	6.253	11.878	9.792	8.172
111	7.437	10.293	7.746	9.205	8.614	6.333
112	9.823	10.781	9.056	12.208	12.618	9.269
LSMean	10.222*a*	9.987*a*	8.877*b*	11.875*a*	9.946*b*	8.343*c*

abc Least square means within steak type with different letters are significantly different (P<0.05).

11. Effect of aging on shear values (kg) of muscles from the hip.

Carcass #	Inside round			Outside round			Eye of round		
	Aging period (days)			Aging period (days)			Aging period (days)		
	3	7	14	3	7	14	3	7	14
101	10.962	8.630	7.294	10.915	12.503	9.508	12.354	8.344	5.651
102	7.523	6.569	9.343	13.373	11.050	10.563	7.332	7.914	4.785
103	13.363	14.420	9.310	13.227	10.491	8.625	8.052	5.577	5.466
104	5.471	4.765	8.473	10.229	8.818	8.806	4.620	7.255	6.246
105	6.777	6.878	6.518	10.792	11.599	9.713	7.603	8.211	6.222
106	6.995	6.739	5.365	15.073	12.097	12.504	10.248	7.639	7.788
107	10.041	7.611	4.734	12.877	14.940	14.660	7.604	8.756	7.860
108	7.341	6.367	5.634	13.660	13.067	11.523	8.355	8.464	7.322
109	7.783	7.608	6.360	8.880	9.397	8.085	6.725	5.634	6.755
110	7.098	5.257	5.813	11.572	9.566	9.085	8.178	11.330	5.886
111	6.697	7.985	5.630	11.878	12.110	11.570	6.294	5.695	6.261
112	8.958	8.766	7.704	11.913	8.000	8.833	6.638	5.501	5.784
LSMean	8.251*a*	7.633*ab*	6.848*b*	12.032*a*	11.136*ab*	10.290*b*	7.833*a*	7.527*ab*	6.335*b*

ab Least square means within steak type with different letters are significantly different ($P<0.05$).

Table 12. Effect of high voltage electrical stimulation on shear values of the loin eye muscle aged for different periods.

Carcass #	Aging period (days)					
	3		7		14	
	Control	**HVES**	**Control**	**HVES**	**Control**	**HVES**
101	9.483	9.141	7.695	8.518	10.849	8.157
102	11.070	7.615	9.880	6.505	11.515	6.044
103	9.446	7.023	10.661	6.566	10.073	5.526
104	12.780	8.891	10.404	6.749	7.277	6.137
105	10.893	11.181	11.188	8.827	9.160	7.558
106	10.231	8.530	8.966	7.079	8.226	6.530
107	13.180	9.908	14.422	8.371	10.966	6.539
108	7.594	5.364	7.069	5.672	8.533	5.746
109	8.732	6.056	10.536	5.893	6.866	5.135
110	11.996	9.213	7.953	7.663	6.2533	7.087
111	7.437	5.700	10.293	5.317	7.746	4.938
112	9.823	8.661	10.781	8.783	9.056	6.208
LSMean	10.222*a*	8.107*b*	9.987*a*	7.162*b*	8.877*a*	6.300*b*

ab Least square means within aging period with different letters are significantly different (P<0.0001).

Table 13. Effect of aging on shear values (kg) of loin eye muscle from high voltage electrically stimulated carcasses.

	Aging period (days)		
Carcass number	3	7	14
101	9.141	8.518	8.157
102	7.615	6.505	6.044
103	7.023	6.566	5.526
104	8.891	6.749	6.137
105	11.181	8.827	7.558
106	8.530	7.079	6.530
107	9.908	8.371	6.539
108	5.364	5.672	5.746
109	6.056	5.893	5.135
110	9.213	7.663	7.087
111	5.700	5.317	4.938
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LSMean	8.107*a*	7.162*b*	6.300*b*

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Table 12. Effect of high voltage electrical stimulation on shear values of the loin eye muscle aged for different periods.

Carcass #	Aging period (days)					
	3		7		14	
	Control	**HVES**	**Control**	**HVES**	**Control**	**HVES**
101	9.483	9.141	7.695	8.518	10.849	8.157
102	11.070	7.615	9.880	6.505	11.515	6.044
103	9.446	7.023	10.661	6.566	10.073	5.526
104	12.780	8.891	10.404	6.749	7.277	6.137
105	10.893	11.181	11.188	8.827	9.160	7.558
106	10.231	8.530	8.966	7.079	8.226	6.530
107	13.180	9.908	14.422	8.371	10.966	6.539
108	7.594	5.364	7.069	5.672	8.533	5.746
109	8.732	6.056	10.536	5.893	6.866	5.135
110	11.996	9.213	7.953	7.663	6.2533	7.087
111	7.437	5.700	10.293	5.317	7.746	4.938
112	9.823	8.661	10.781	8.783	9.056	6.208
LSMean	10.222*a*	8.107*b*	9.987*a*	7.162*b*	8.877*a*	6.300*b*

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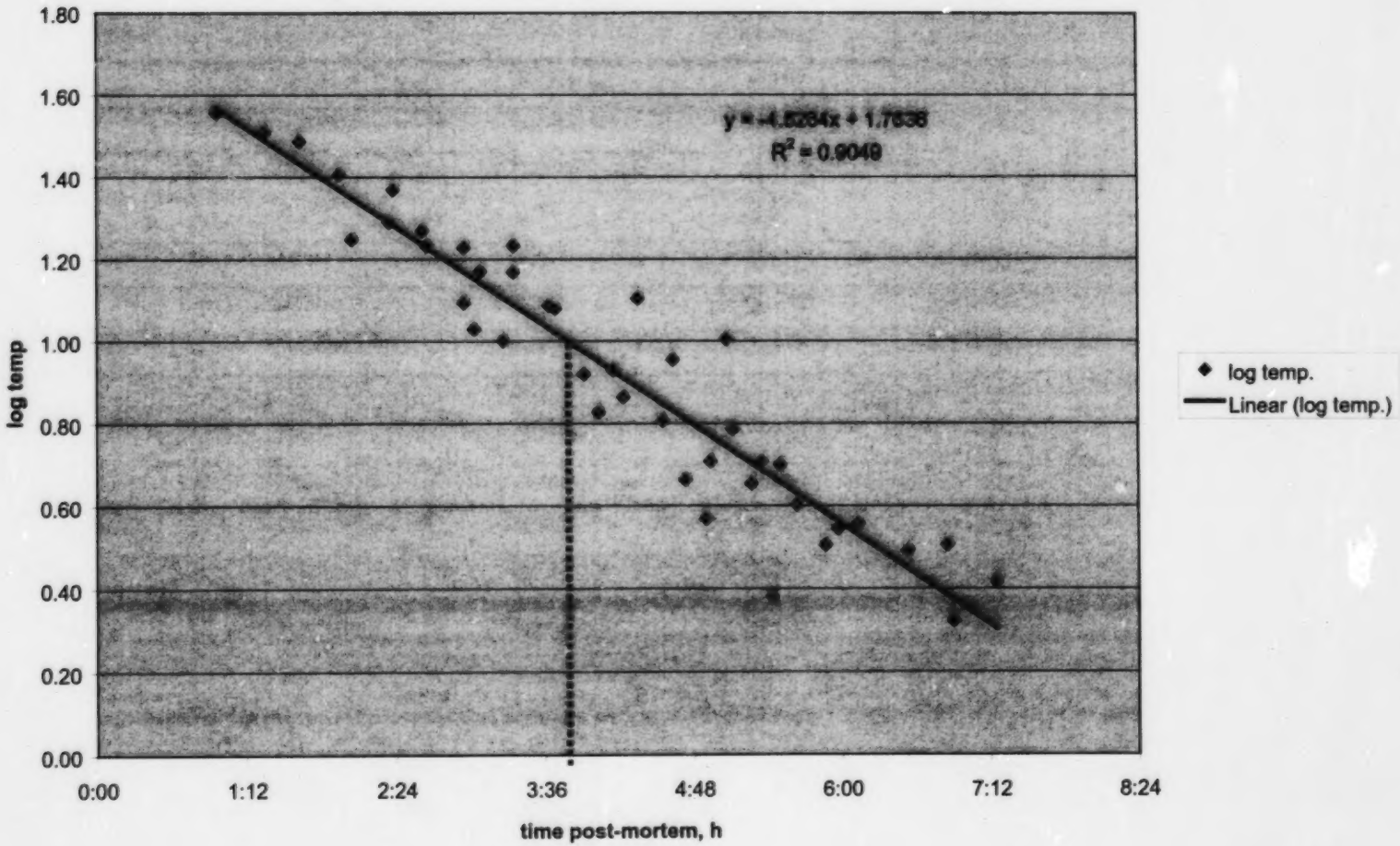
109	6.056	5.893	5.135
110	9.213	7.663	7.087
111	5.700	5.317	4.938
112	8.661	8.783	6.208
LSMean	8.107*a*	7.162*b*	6.300*b*

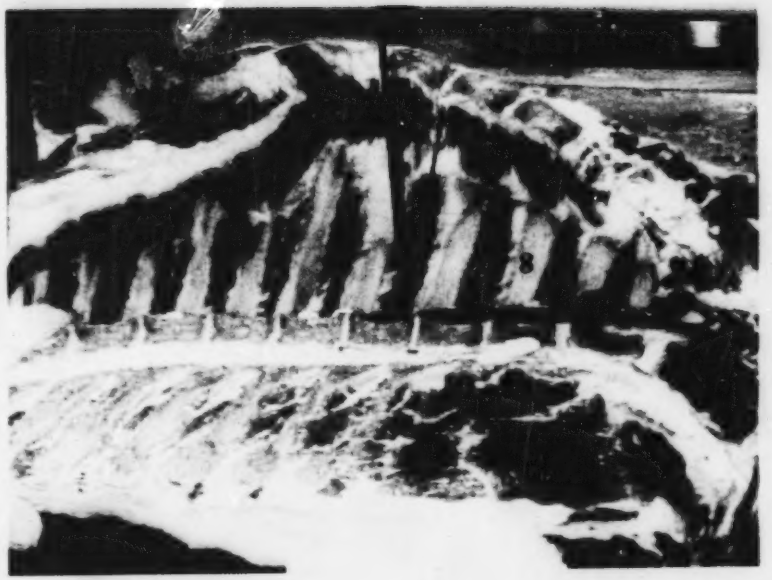
ab Least square means with different letters are significantly different ($P<0.05$).

Appendix 1. Log of temperature decline in rib eye muscle of llama carcasses chilled at 1°C



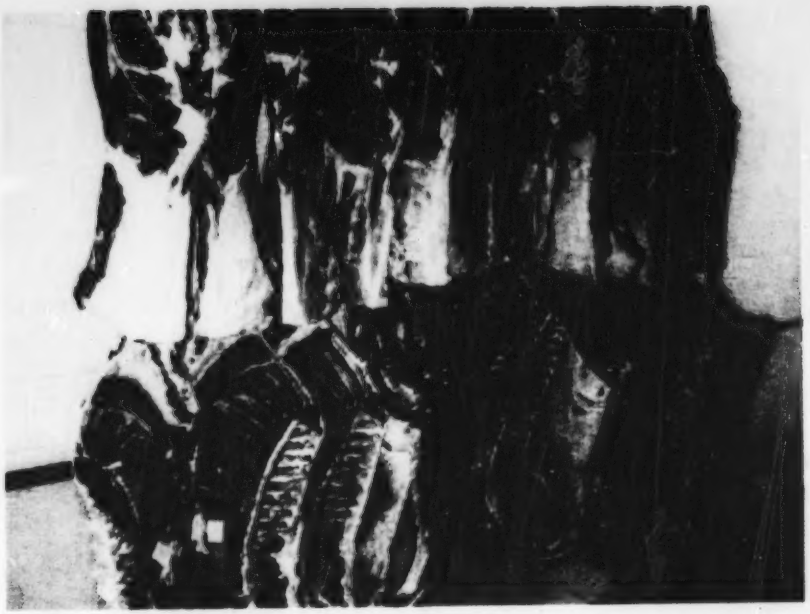
Illustrations of llama cuts from the trial

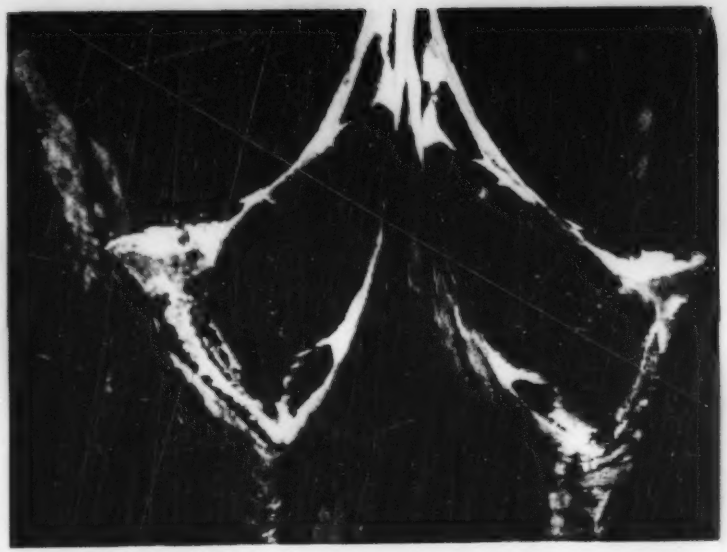
1. Round or leg
2. 1 x 1 Long loin
3. Flank
4. 2 x 3 Rib (7-bone)
5. Plate
6. Neck
7. Shank
8. Four-bone chuck with brisket attached.

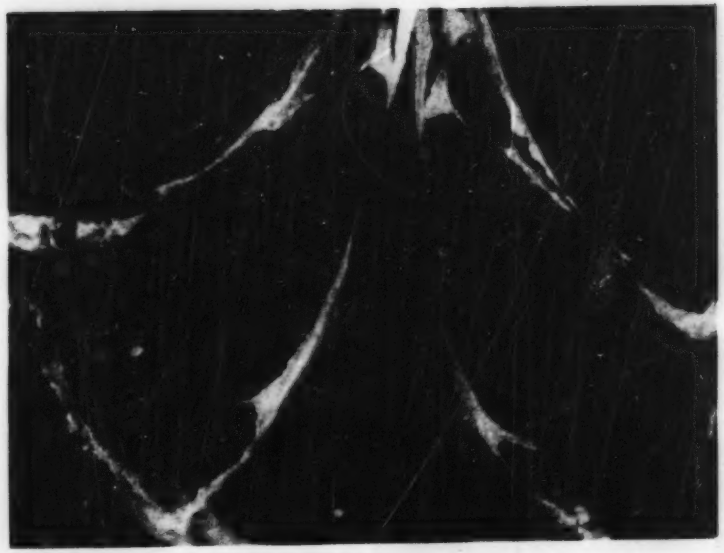


Llama carcass side showing insertion of lower electrode for high voltage electrical stimulation

Contraction of the carcass side during application of HVES current

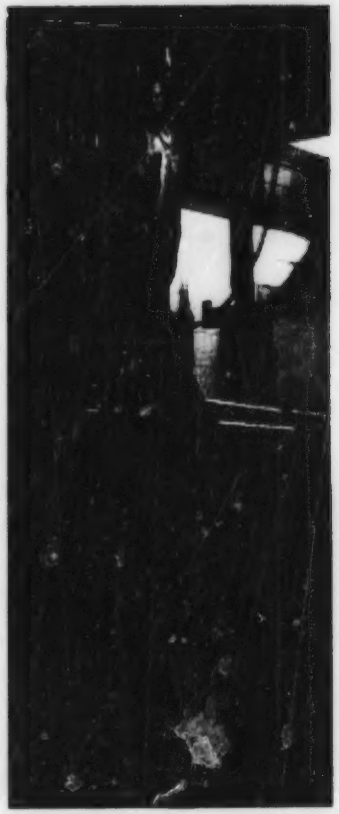






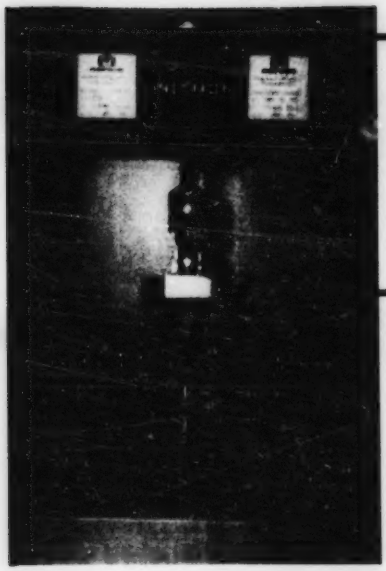
Above: llama carcass sides knife-ribbed at the 11/12th rib

Right: Examples of llama rib eyes showing fat cover, degree of marbling and differences in muscle color.



Llama carcass side showing insertion of lower electrode for high voltage electrical stimulation

Contraction of the carcass side during application of HVES current



Instron Materials Testing System and Warner-Bratzler shear cell for determination of shear values

Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada
Canada